Density Distributions and Power Spectra of Outflow-Driven Turbulence

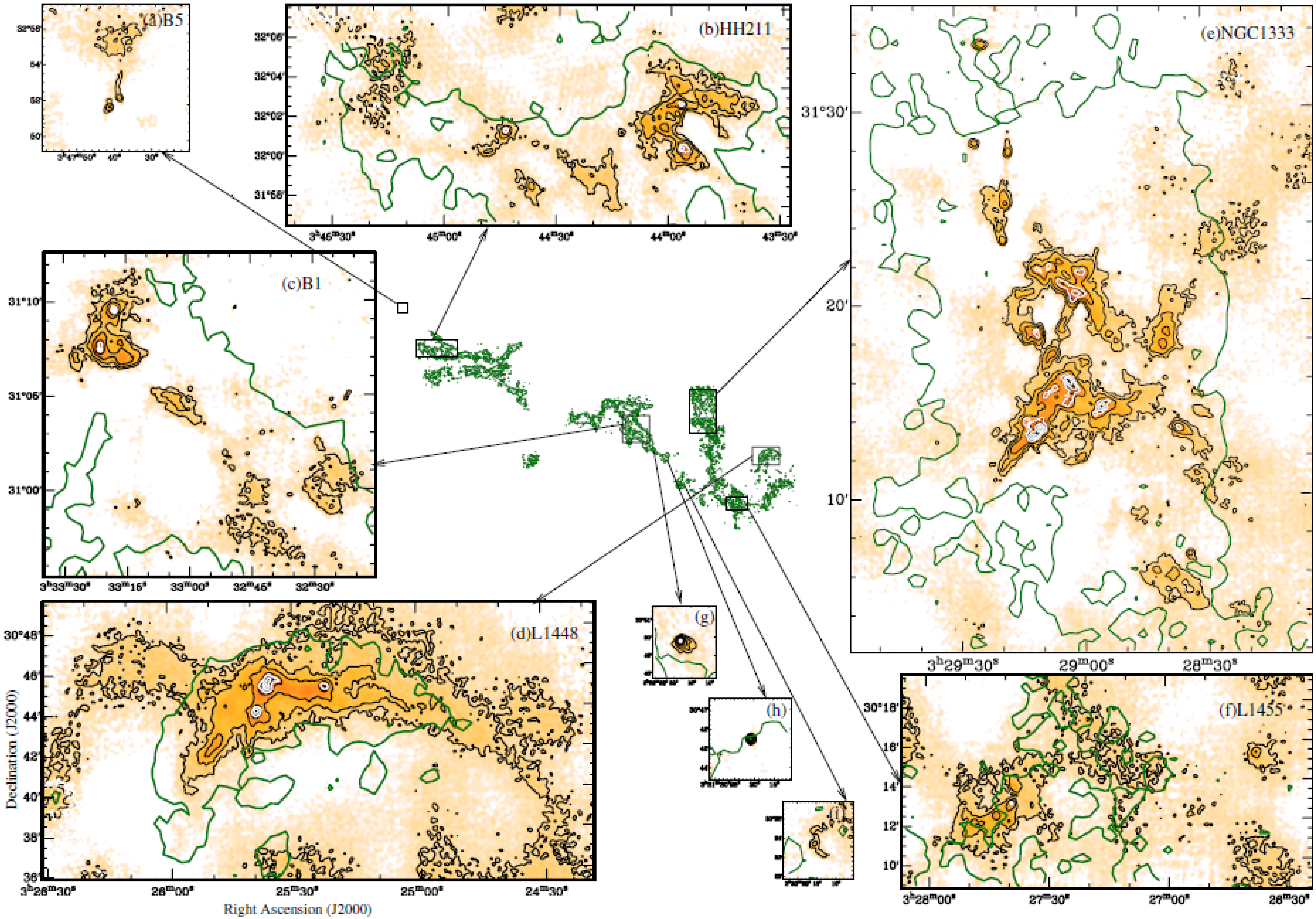
Jongsoo Kim (KASI)

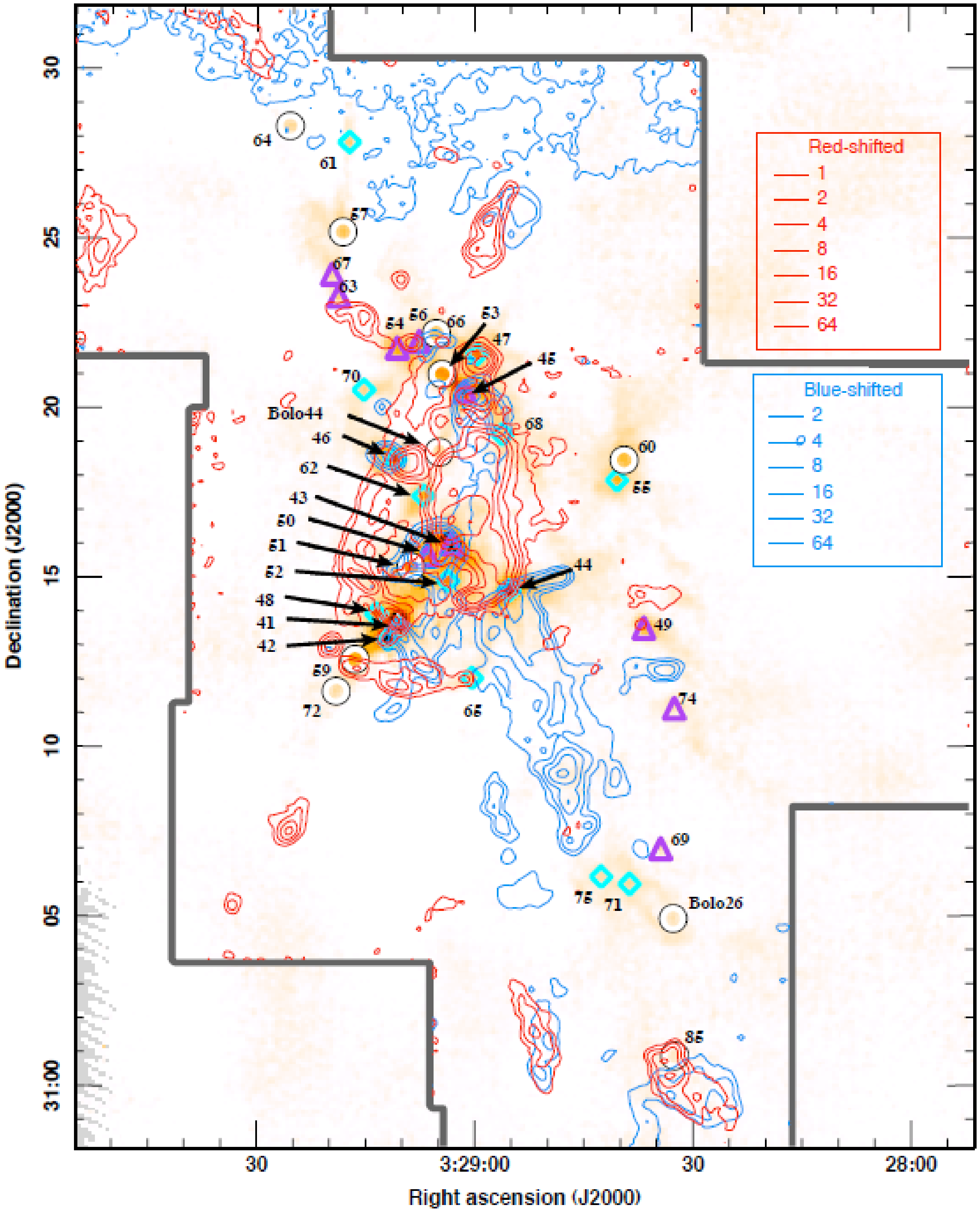
based on two published papers

Moraghan, Kim, Yoon 2013, MN, 432, 80

Moraghan, Kim, Yoon 2015, MN, 450, 360

Hatchell+ 2005

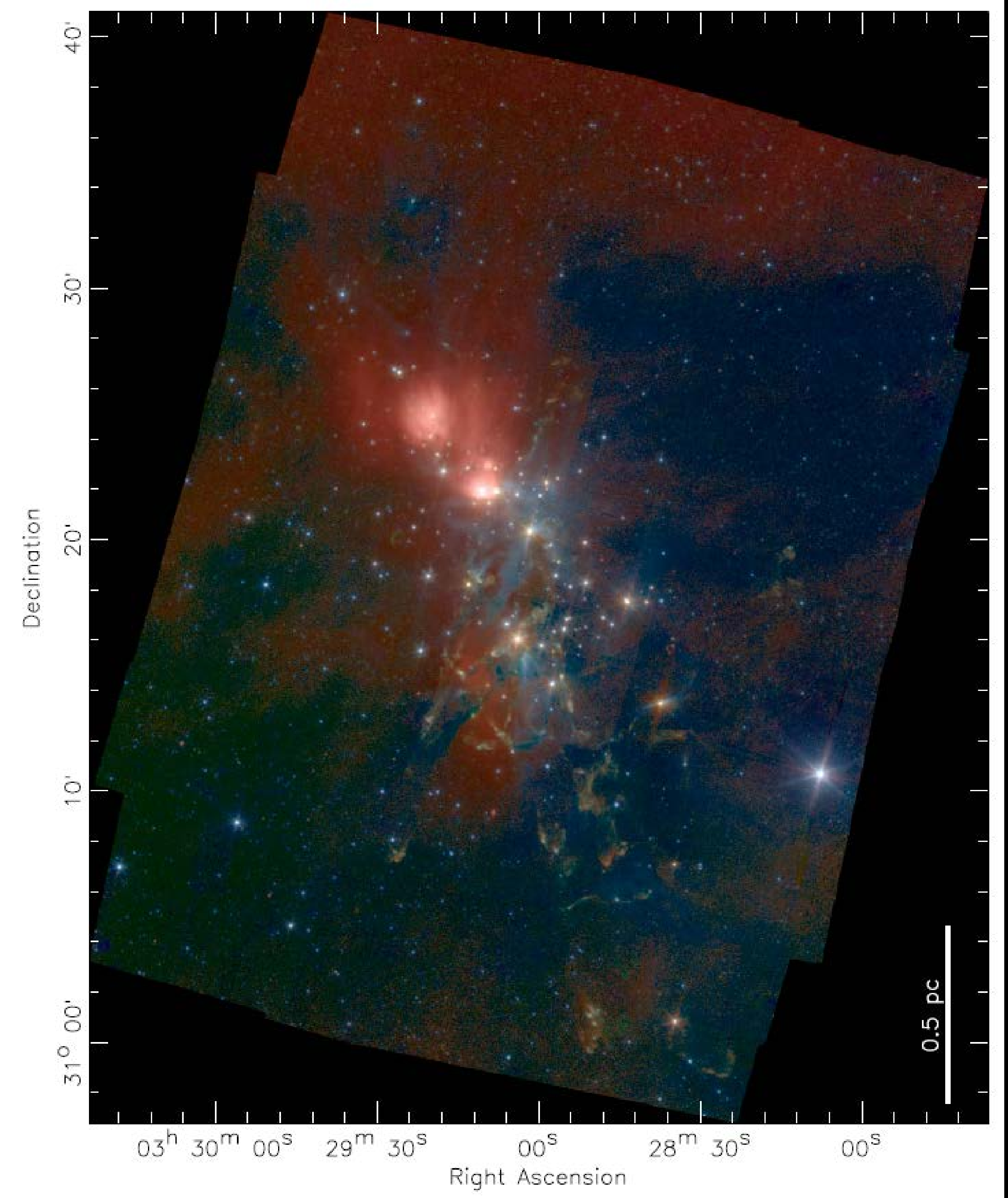




Curtis+ 2010

SCUBA 850um: color image

CO J=3-2 integrated Intensity
blue: -5 ~ 3 km/sec
red: 12 ~ 18 km/sec

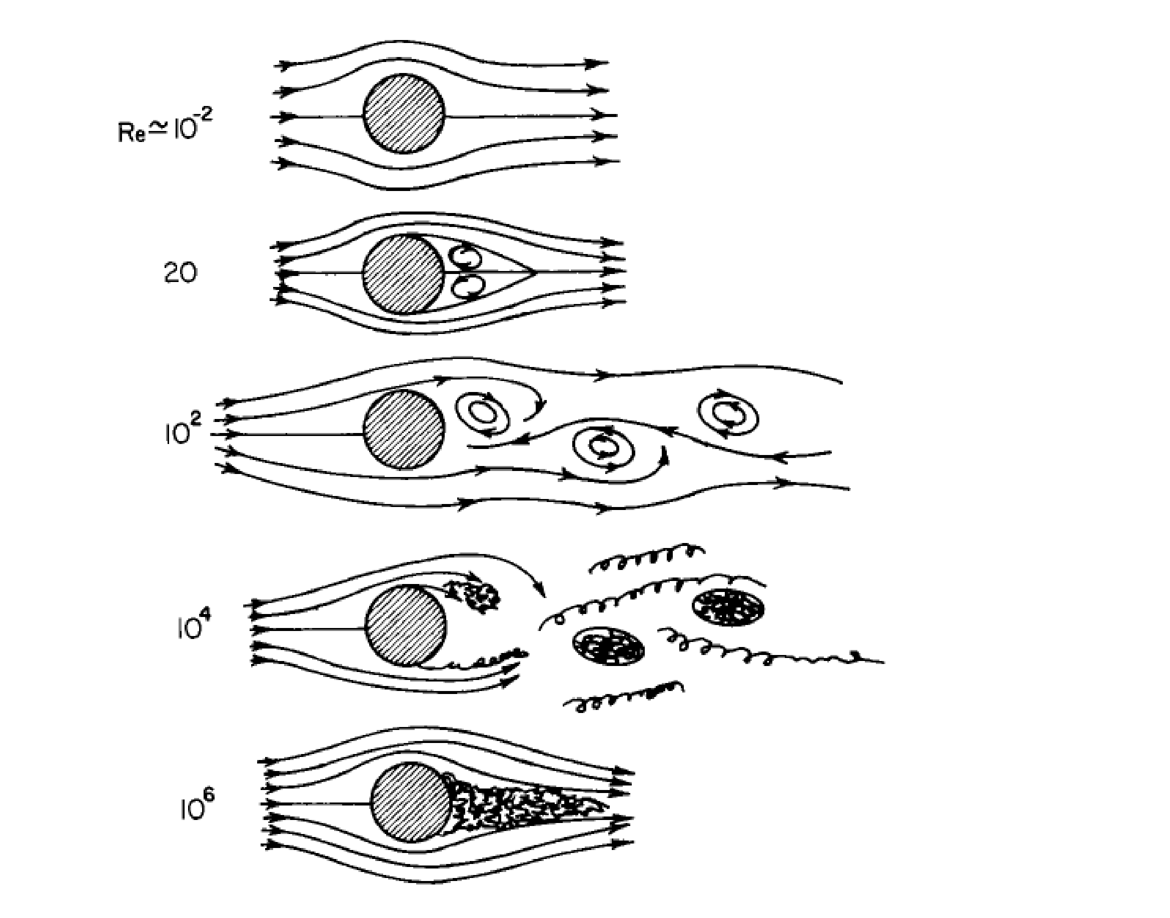


Gutermuth+ 2008
Spitzer
3.6,4.5,8.0 micron
blue, green, red

Reynolds number

$$\rho\left(\frac{\partial \mathbf{v}}{\partial t}+\mathbf{v}\cdot\nabla\mathbf{v}\right)=-\nabla p+\mu\nabla^2\mathbf{v}+\mathbf{f}$$

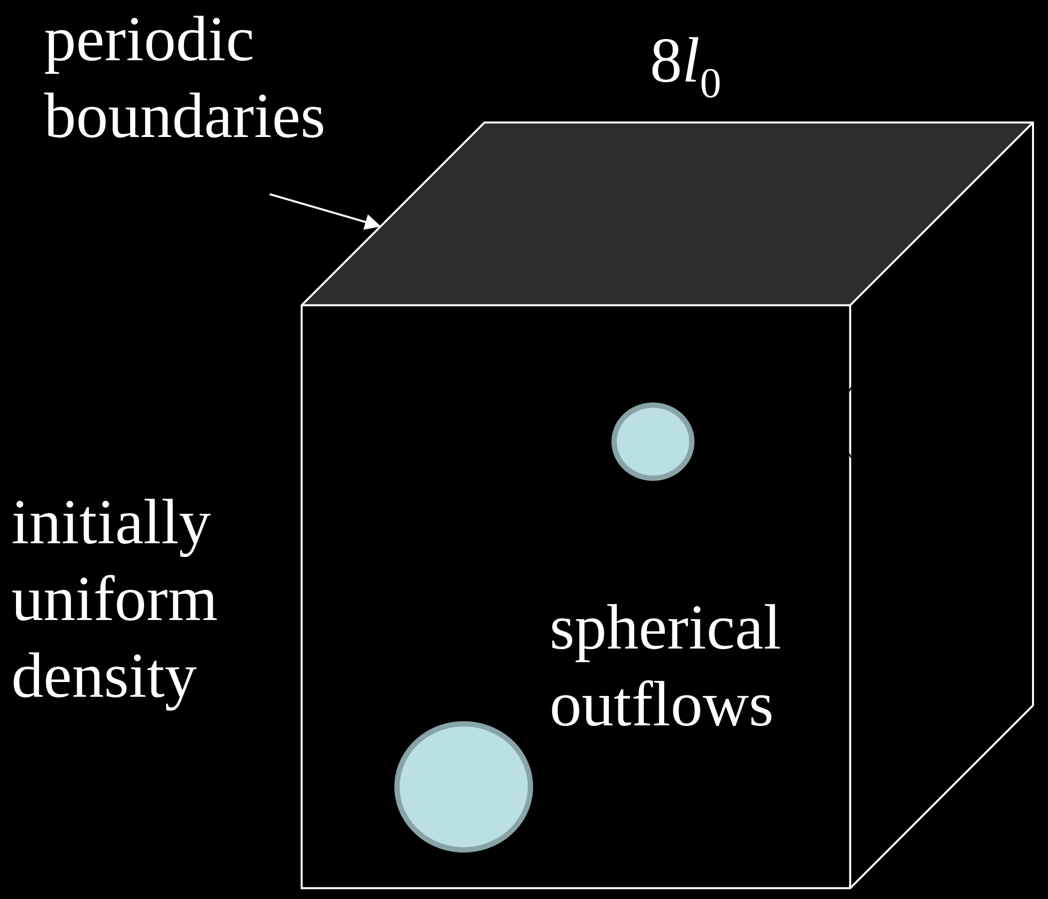
$$\mathrm{Re}=\frac{UL}{\nu}=10^6\left(\frac{U}{1\mathrm{km/sec}}\right)\left(\frac{L}{1\mathrm{pc}}\right)\left(\frac{n}{100\mathrm{cm}^{-3}}\right)\left(\frac{T}{10\mathrm{K}}\right)^{-1/2}$$



Motivation

- Most numerical simulations on the ISM turbulence were driven in the Fourier space, which is not realistic.
- We studied density PDF, and density and velocity PS of our outflow-driven turbulence in the NGC1333 region through numerical experiments.

3D, isothermal, outflow-driven HD simulations



resolution: 1024^3 cells

Basic equations and dimensionless units

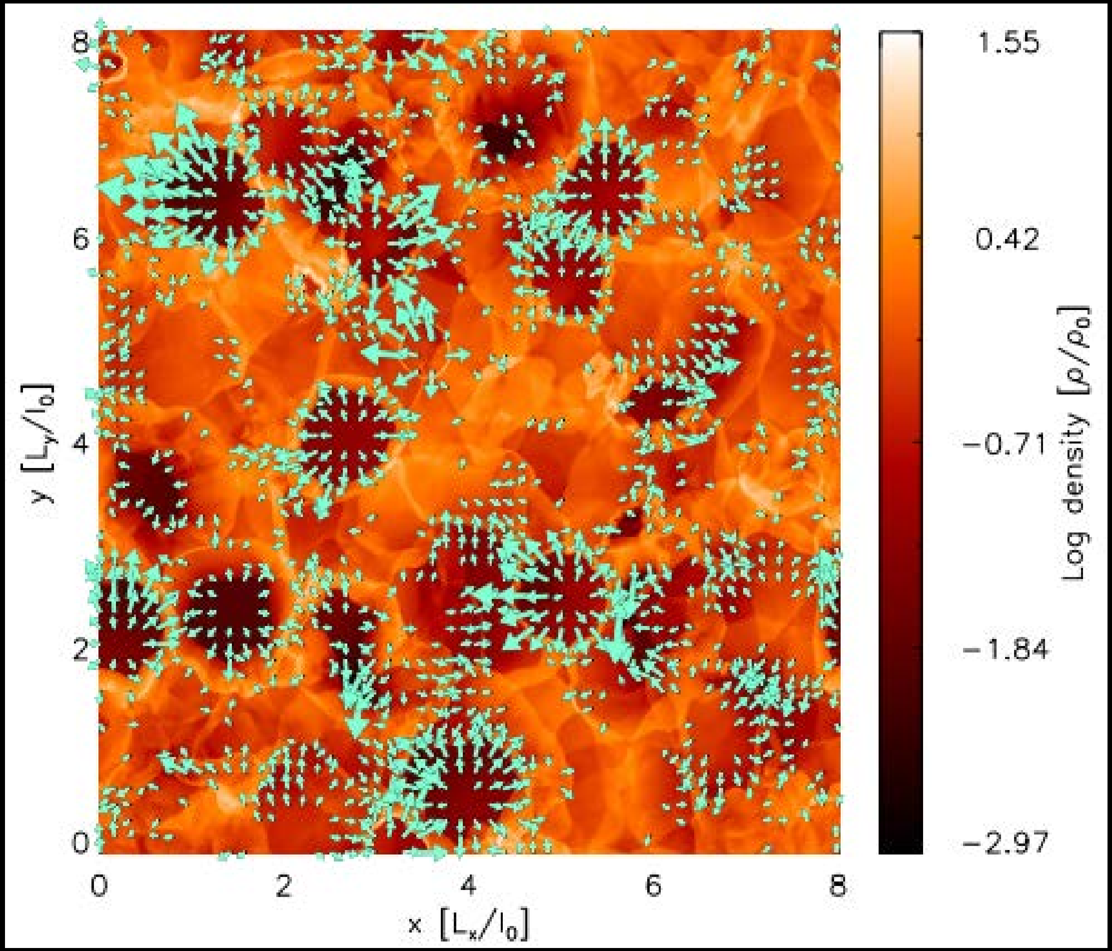
$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0;$$

$$\rho\left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v}\right) + \nabla\left(\rho a^2\right) = f;$$

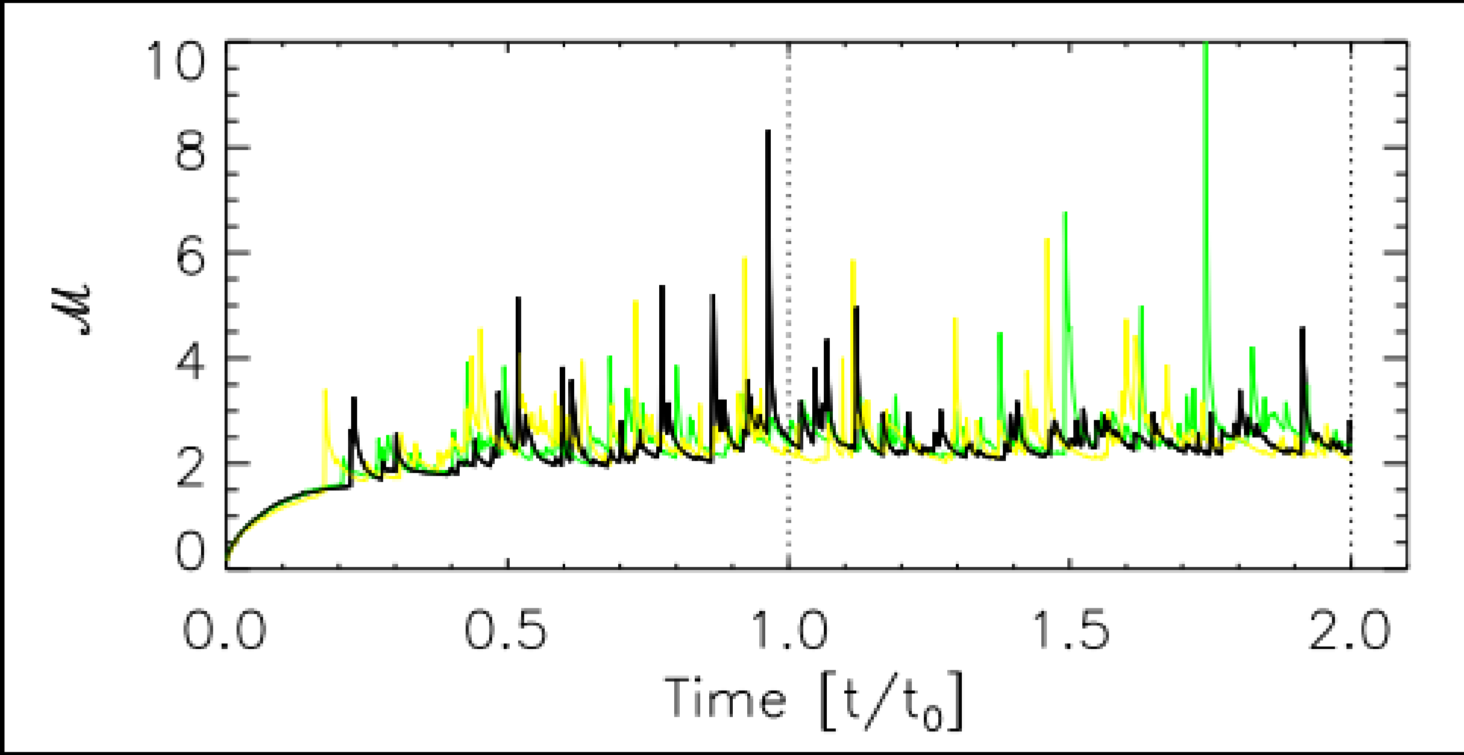
$$m_0 = \frac{\rho^{\frac{4}{7}} P^{\frac{3}{7}}}{S^{\frac{3}{7}}},\ l_0 = \frac{P^{\frac{1}{7}}}{\rho^{\frac{1}{7}} S^{\frac{1}{7}}},\ \text{and}\ t_0 = \frac{\rho^{\frac{4}{7}}}{P^{\frac{3}{7}} S^{\frac{4}{7}}}$$

- $\rho=2.51\times10^{-20}$ gcm^{-3}
- $P=3.98\times10^{39}$ $gcm^{-3}s^{-1}$
- $S=6.31\times10^{-68} cm^{-3}s^{-1}$
- m_0 = 18.7Msun, l_0 = 0.37pc, t_0=*0.34* Myr, $v_0=l_0/t_0$=1.064km/sec

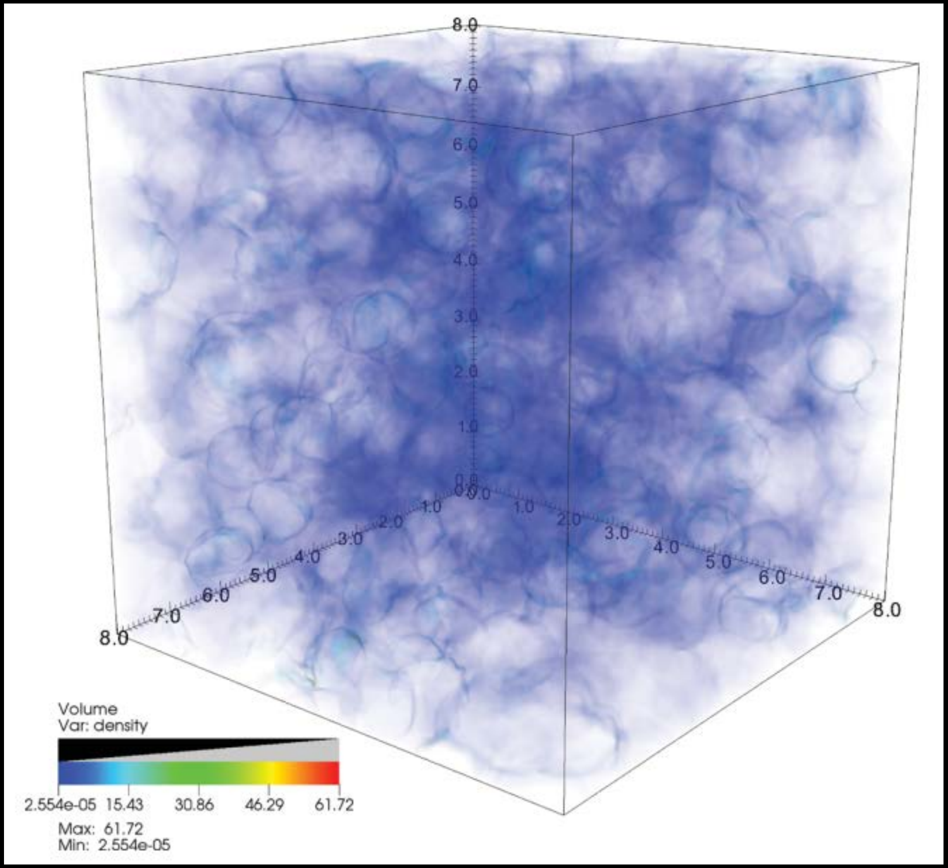
Snapshot of density and velocity field

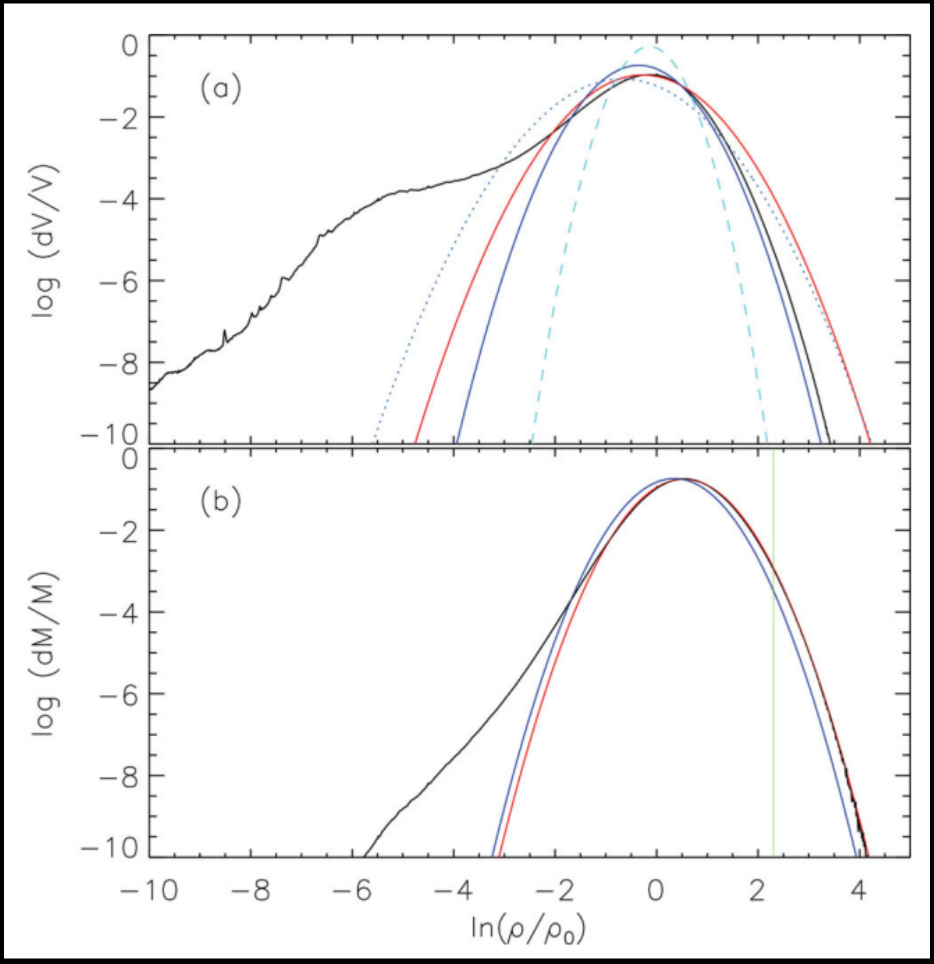


Evolution of Mach number

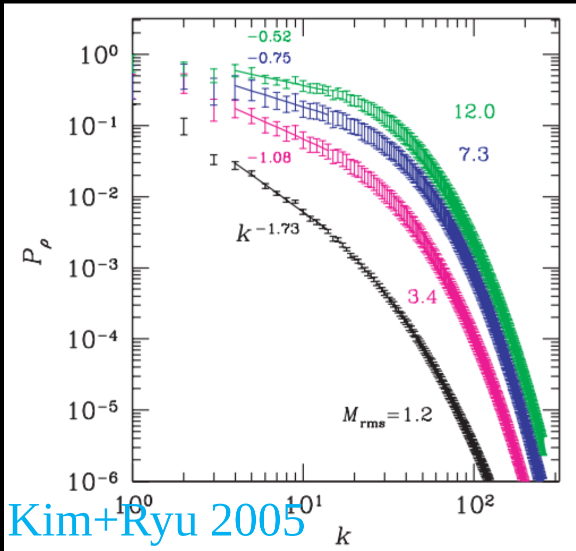


3D density, density PDFs

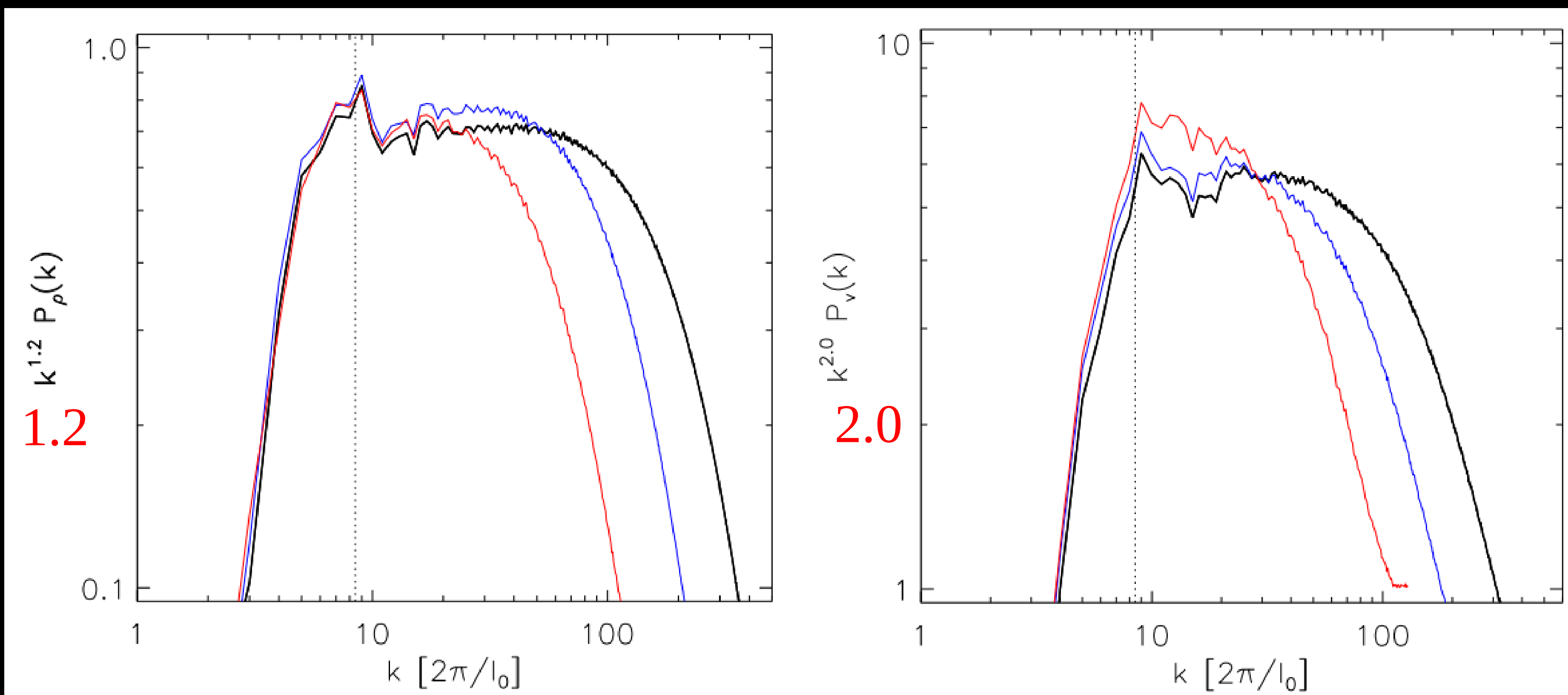




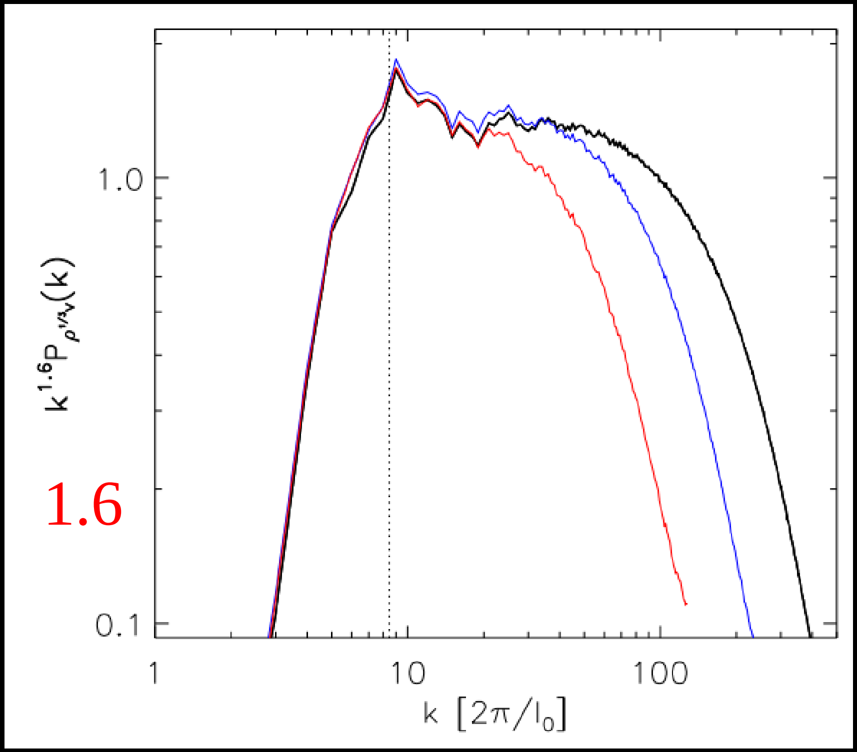
Density and velocity PS



Kim+Ryu 2005



Universality of Density-weighted velocity PS?

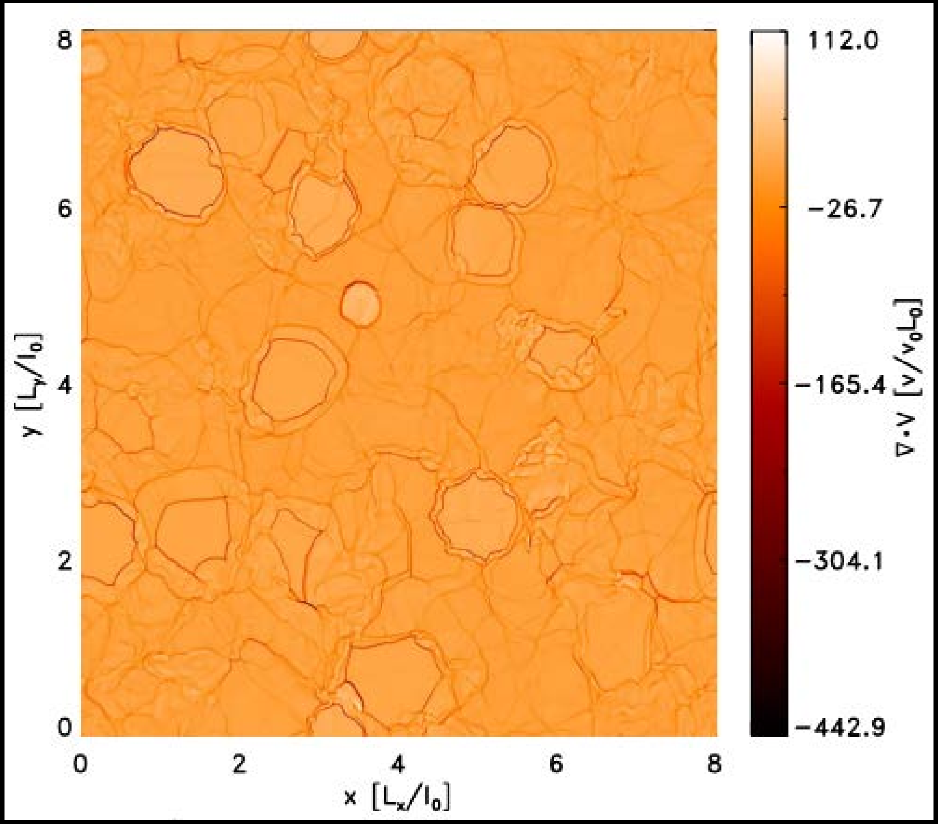


$$P(\rho^{1/3} v) \propto$$

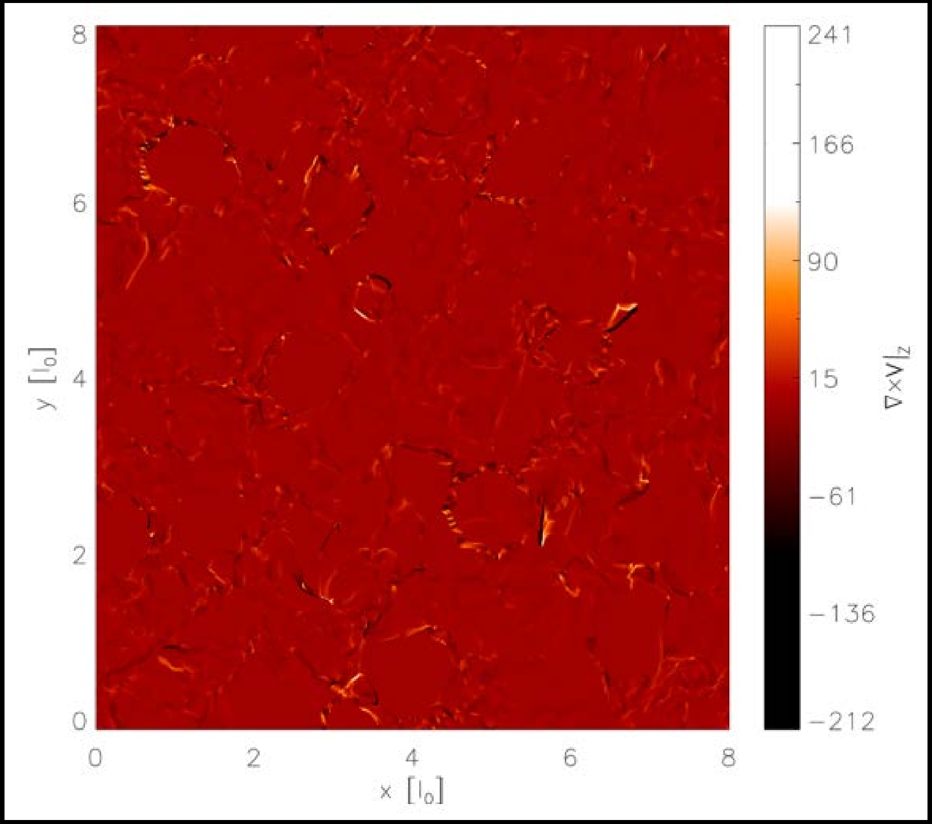
k^{-5/3} Kolmogorov
k^{-1.74} solenoidal driving
k^{-2.10} for compressional driving

Div v

curl v

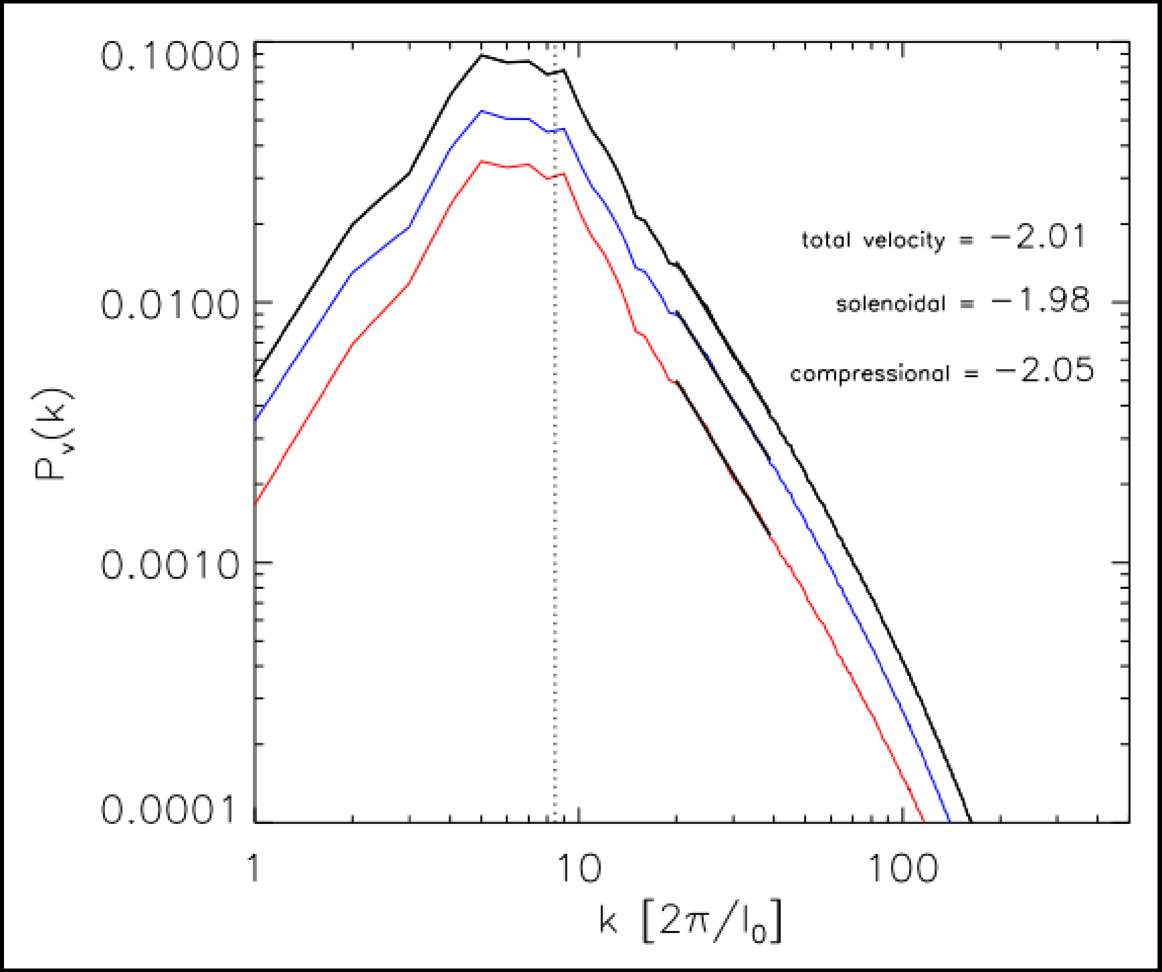


8
6
4
2
0
y [L_y/l_0]
0
2
4
6
8
x [L_x/l_0]
112.0
−26.7
−165.4
−304.1
−442.9
∇·V [v/v_0L_0]

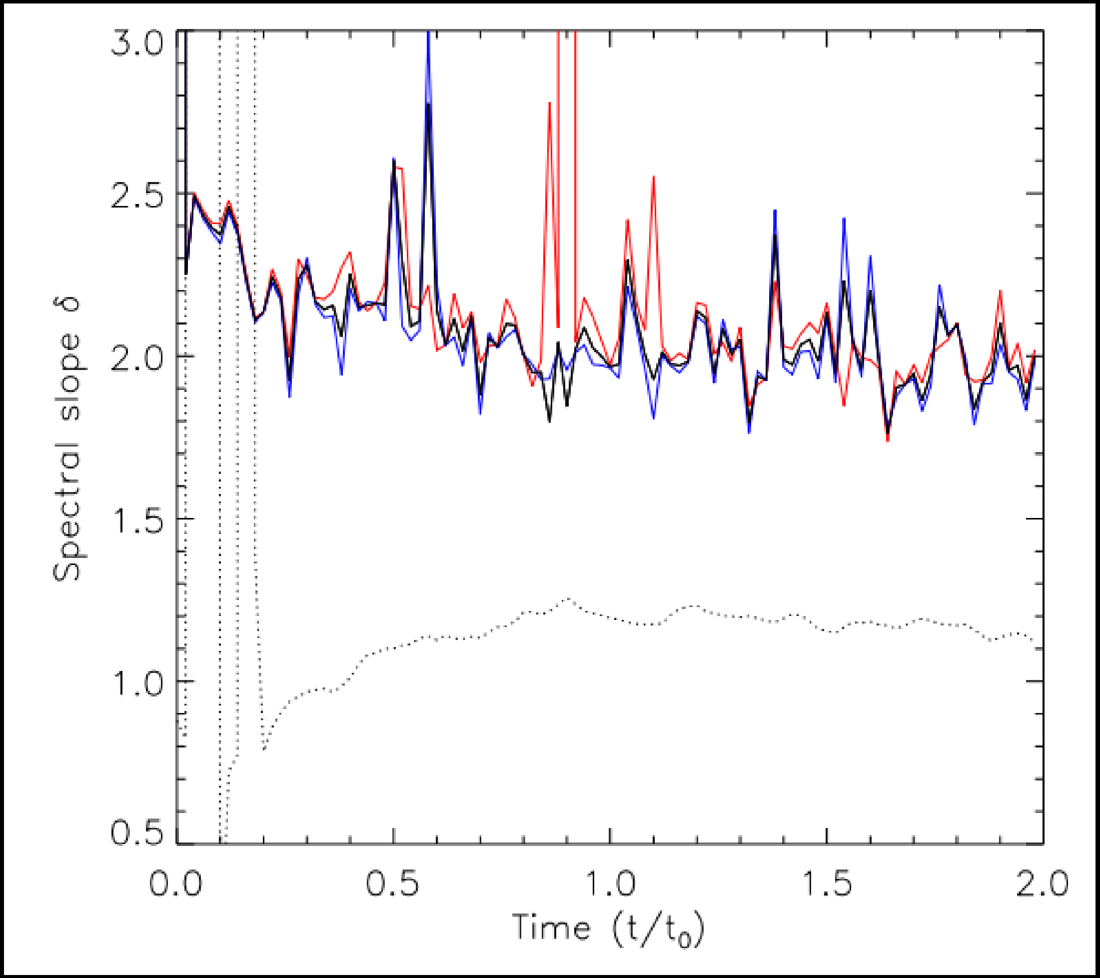


8
6
4
2
0
y [l_0]
0
2
4
6
8
x [l_0]
241
166
90
15
−61
−136
−212
$\nabla\times V|_z$

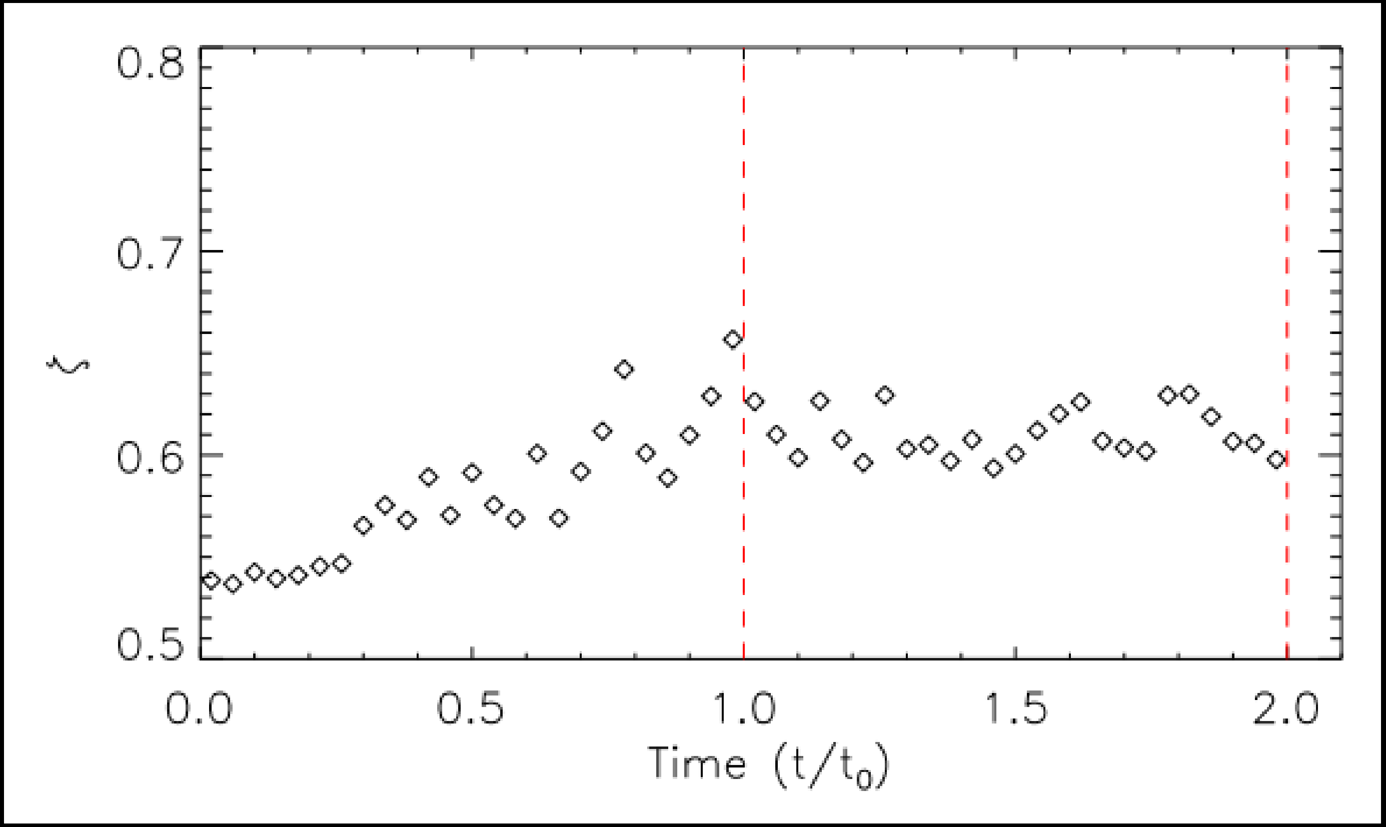
vPS: Solenoidal vs. compressional

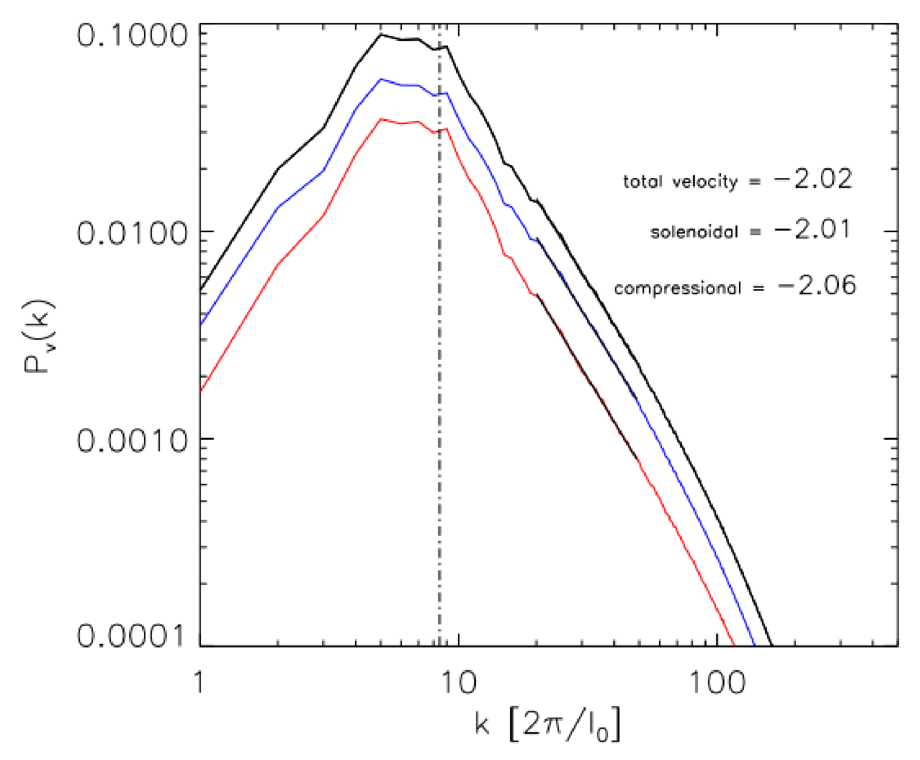


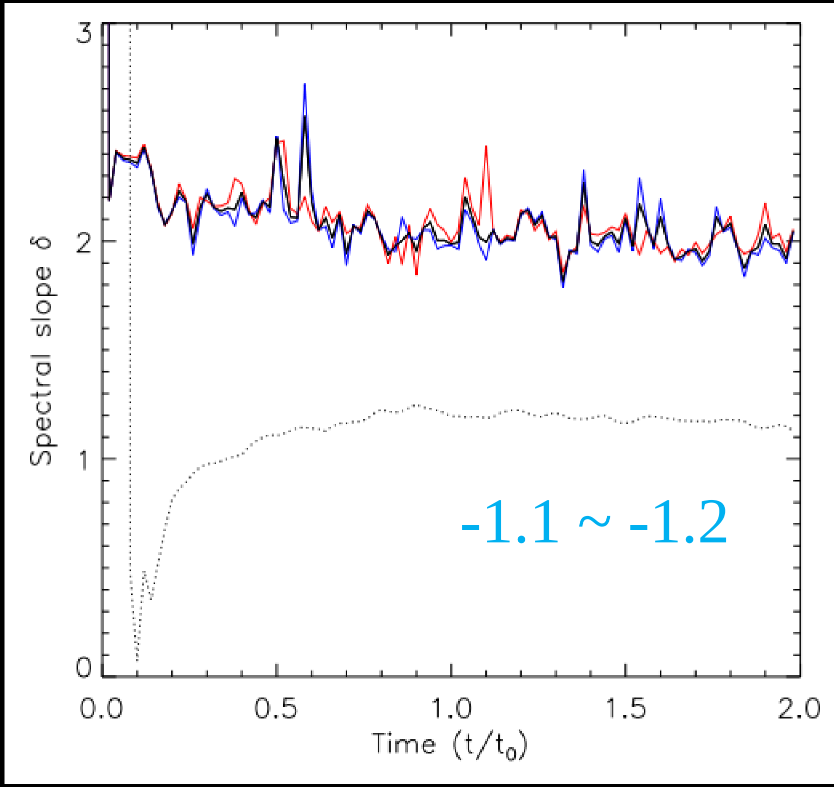
Evolution of spectral slopes

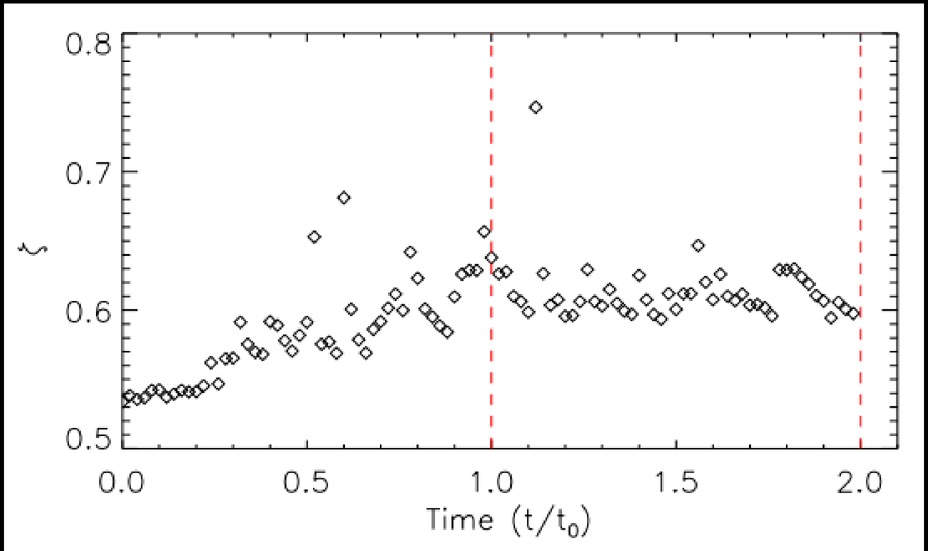


Evolution of solenoidal to total velocity components









zeta = 1: pure solenoidal

zeta = 0: pure compressible

Conclusions

- Outflow-driven turbulence has a negative skewed density PDF with an enhanced tail on the low-density side
- The spectral indexes of density and velocity PS are -1.2 and -2.0, respectively.
- There might be no universal scale law for compressible turbulence flows.
- Supersonic turbulence tries to have a statistically converged ratio of solenoidal to compressible velocity components, i.e., 2:1.